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Acoustic pressure sensing with hollow-core photonic bandgap fibers

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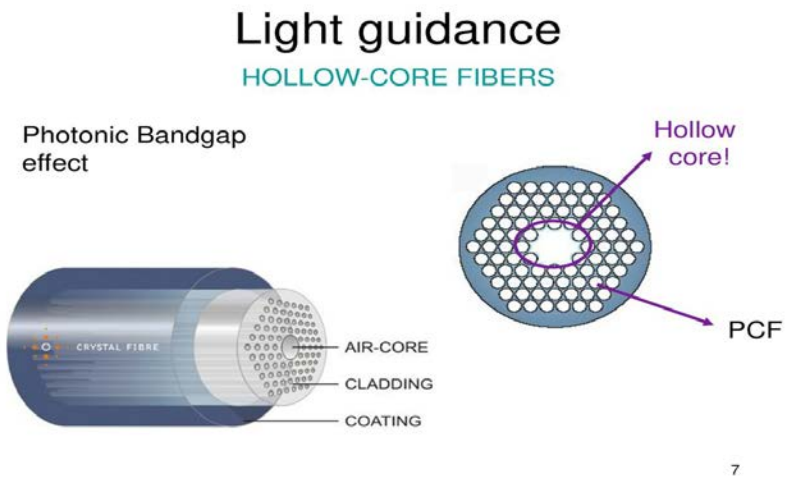
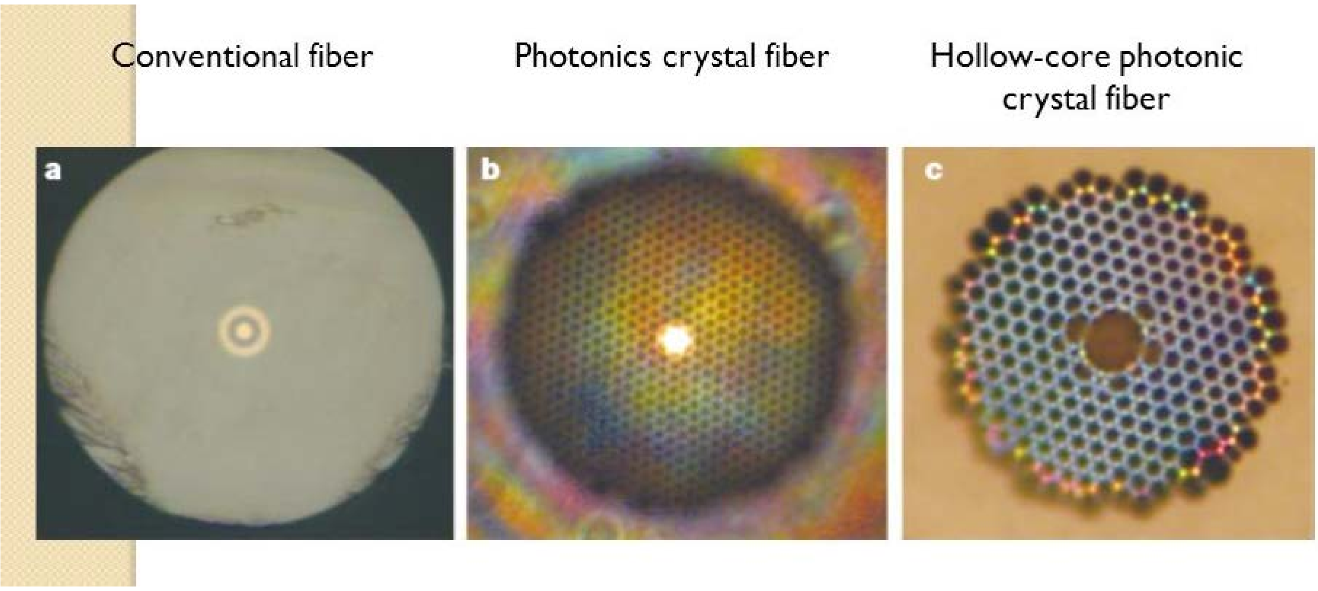
Section	:	C1
Project Group	:	Photonic Bandgap Fiber
Course No.	:	EEE 4518

INTRODUCTION:

Acoustic sensors based on the interferometric detection of pressure-induced phase shift of light propagating inside an optical fiber can be dated back to over 30 years ago. As acoustic pressure changes, both the fiber length L and the mode index n_{eff} (affected by the fiber transverse dimensions and the refractive indices of the materials forming the fiber) change, which result in a change in the signal phase. This undesirable "negative" index effect is anticipated to be greatly reduced in a HC-PBF in which most of the mode energy is confined in air. Since the current commercial HC-PBFs have similar coating materials and outer diameters as compared to conventional fibers, the NR of the HC-PBF is expected to be better. Furthermore, the flexibility offered by the stack-and-draw process, typically used for HC-PBF manufacturing, would allow HC-PBFs with larger area of holey microstructured region and smaller area of solid cladding region to be manufactured.





I report the results of my preliminary simulation on the use of hollow-core photonic bandgap fiber (HC-PBF) for hydrophone application.

Project Progress

[1] Parameters:

Parameters

Name	Expression	Value	Description
a	5.45[um]	5.45E-6 m	Air core radius
b	35[um]	3.5E-5 m	Honeycomb Cladding radius
c	60[um]	6E-5 m	Silica Cladding radius
d	110[um]	1.1E-4 m	Acrylate Cladding
n	10	10	Number of Honeycomb core in a row
dia	eta*pitch	3.648E-6 m	Honeycomb core diameter
pitch	3.8[um]	3.8E-6 m	central distance between adjacent air holes
eta	96/100	0.96	Air filling ratio
silica_refl...	1.4378	1.4378	silica cladding refractive index
L	1[m]	1 m	Cable length
r	dia/2	1.824E-6 m	Honeycomb core radius
c_silica	5760[m/s]	5760 m/s	Velocity of longitudinal wave (extensional wave) in thin rods.
c_pmma	2.8e3[m/s]	2800 m/s	Velocity of sound in Poly Methyl Acrylate[PMMA]
n_pmma	1.4906	1.4906	Refractive index of PMMA
freq	1[THz]	1E12 Hz	Mode analysis frequency

HC 1550-2 PBF_Circular Honeycomb

Parameters

Name	Expression	Value	Description
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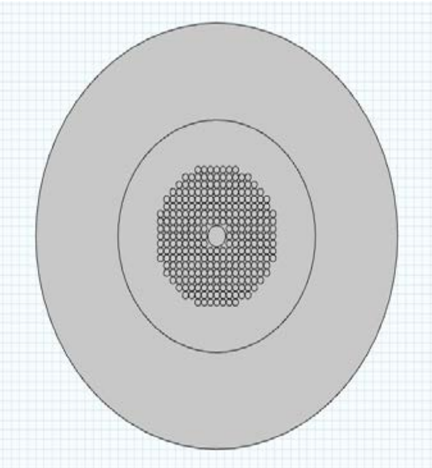
HC 1550-2 PBF_Hexagonal Honeycomb

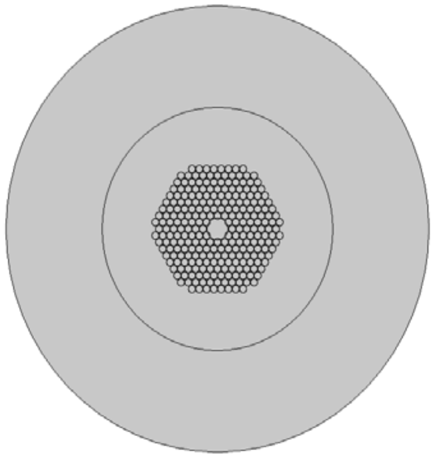
[2] Geometry:

- HC 1550-2 PBF
  - Acrylate Cladding (c1)
  - Honeycomb Core (c8)
  - Honeycomb Array (arr1)
  - Honeycomb Array 2 (arr3)
  - Honeycomb Array 2.1 (arr4
  - Honeycomb Array 2.1.1 (ar
  - Silica Cladding (c2)
  - Difference 1 (dif1)
  - Honeycomb Core 1 (c9)
  - Honeycomb Array 1 (arr6)
  - Honeycomb Array 2.2 (arr7
  - Honeycomb Array 2.1.2 (ar
  - Honeycomb Array 2.1.1.1 (
  - Air core 1 (c10)
  - Union 2 (uni2)
  - Partition Domains 1 (pard1,
  - Form Union (fin)



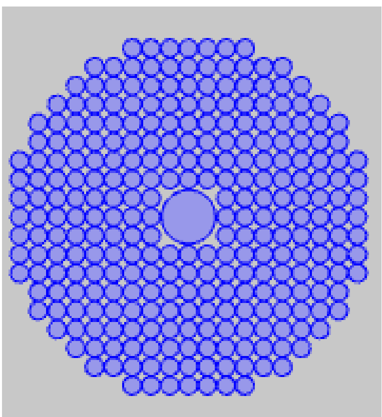
HC 1550-2 PBF_Circular Honeycomb

- HC 1550-2-PBF
  - Acrylate Cladding (c4)
  - Silica Cladding (c3)
  - Difference 1 (dif1)
  - Silica Cladding 1 (c5)
  - Honeycomb Core (c1)
  - Honeycomb array 1 (arr1)
  - Honeycomb array 2 (arr2)
  - Honeycomb array 3 (arr3)
  - Delete Entities 1 (del1)
  - Mirror 1 (mir1)
  - Delete Entities 2 (del2)
  - Center Core (c2)
  - Difference 2 (dif2)
  - Honeycomb Core 1 (c6)
  - Honeycomb array 1.1 (arr4)
  - Honeycomb array 2.1 (arr5)
  - Honeycomb array 3.1 (arr6)
  - Delete Entities 3 (del3)
  - Mirror 2 (mir2)
  - Delete Entities 4 (del4)
  - Center Core 1 (c7)
  - Form Union (fin)

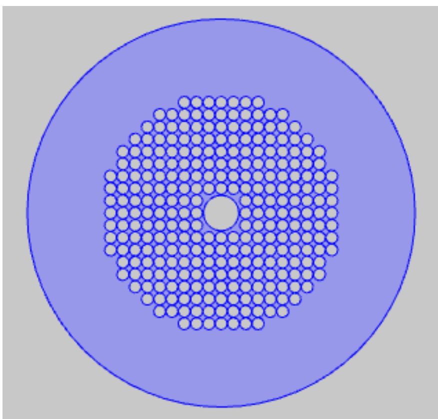


HC 1550-2 PBF_Hexagonal Honeycomb

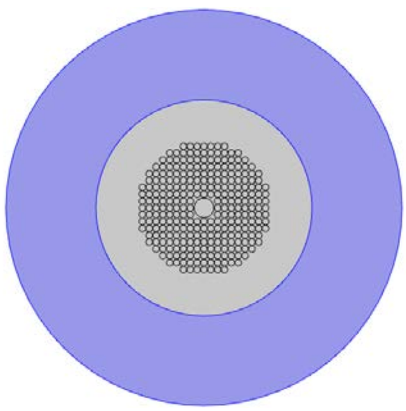
[3] Materials Added:



(i) Air

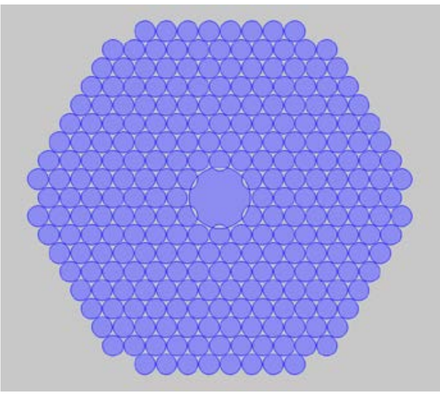


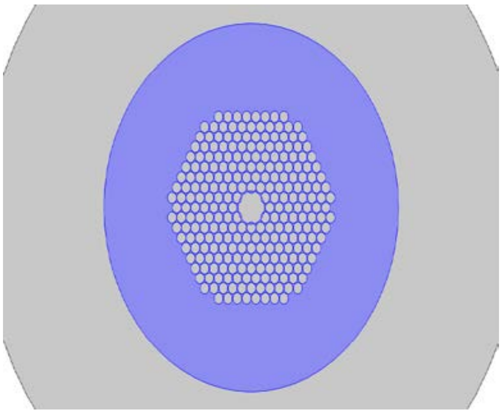
(ii) Silica Glass

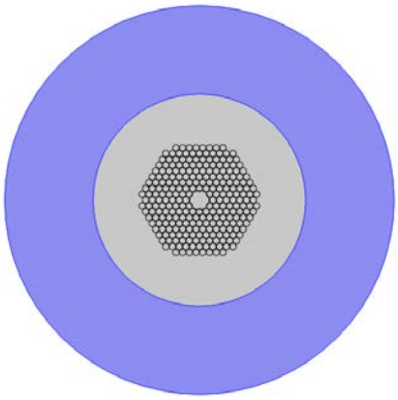


(iii) Poly Methyl Meta-Acrylate

HC 1550-2 PBF_Circular Honeycomb



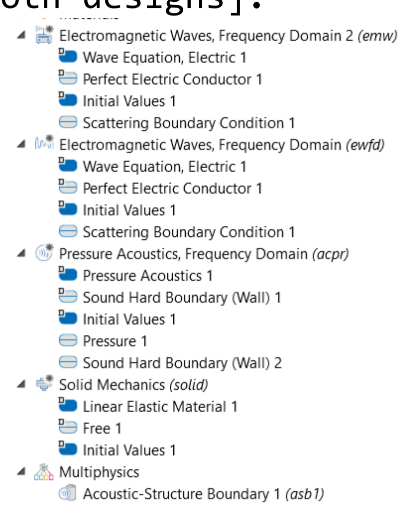




(i) Air **(ii) Silica Glass** **(iii) Poly Methyl Meta-Acrylate**

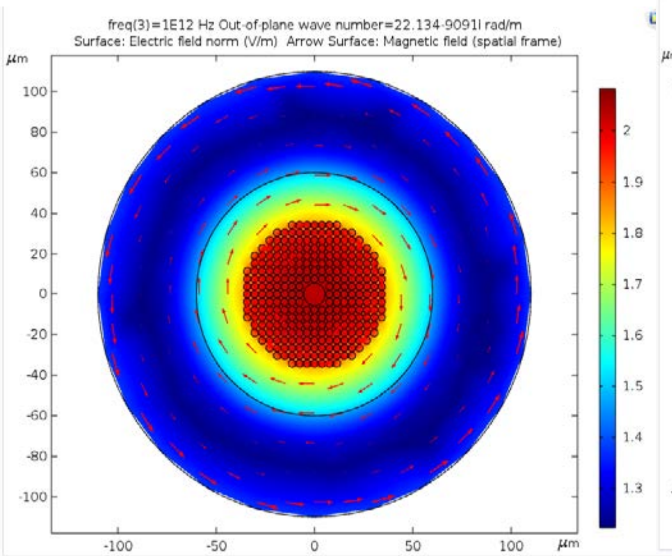
HC 1550-2 PBF_Hexagonal Honeycomb

[4] Physics Used [For both designs]:

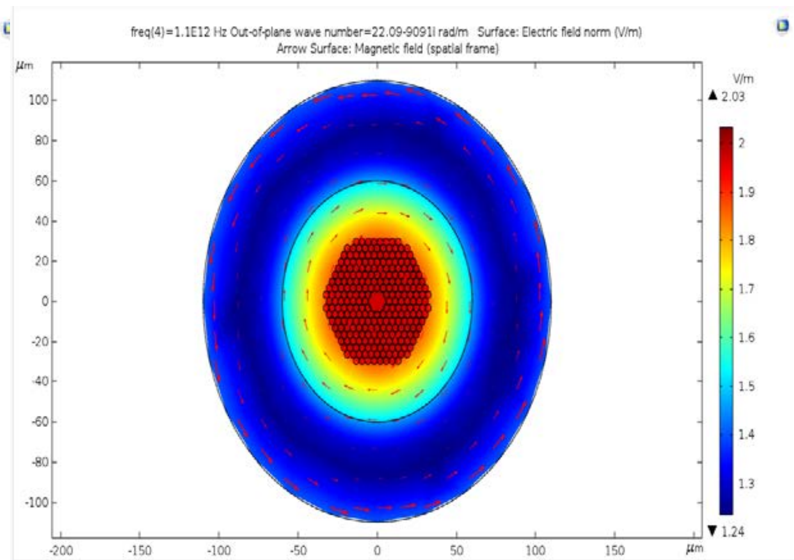


[5] Result:

(a) Electric Field

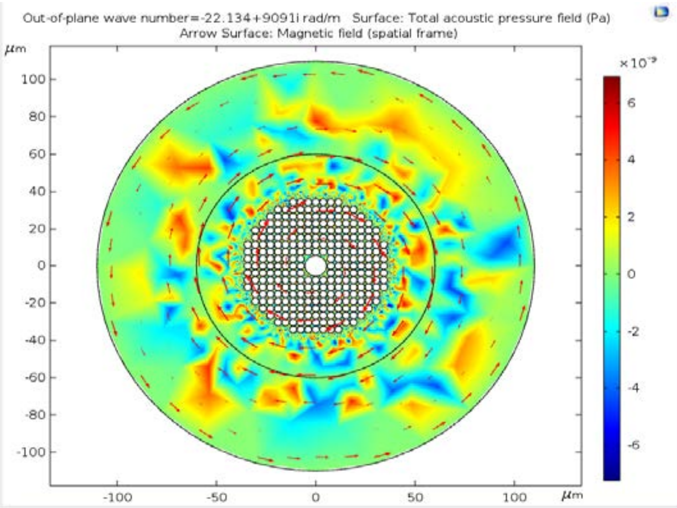


HC 1550-2 PBF_Circular Honeycomb

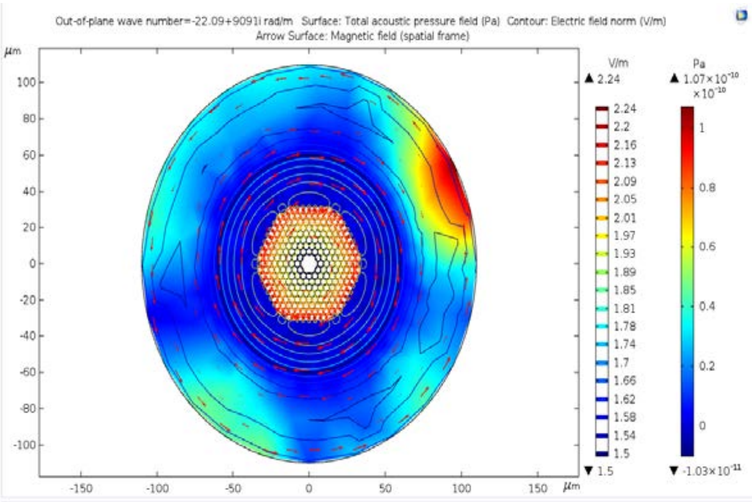


HC 1550-2 PBF_Hexagonal Honeycomb

(b) Acoustic Pressure

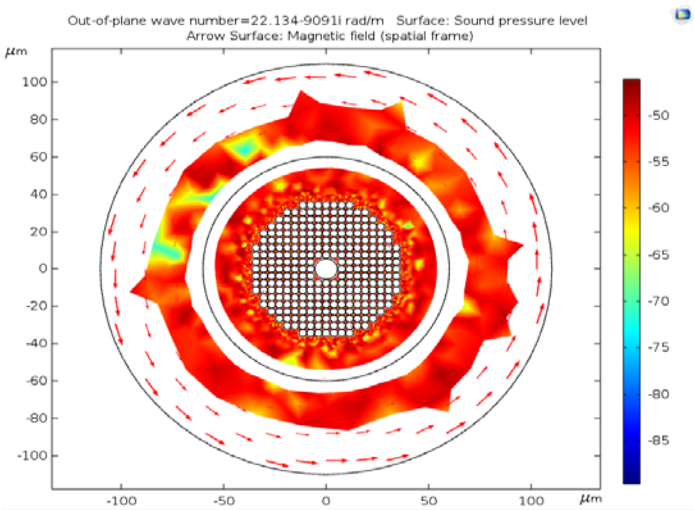


HC 1550-2 PBF Circular Honeycomb

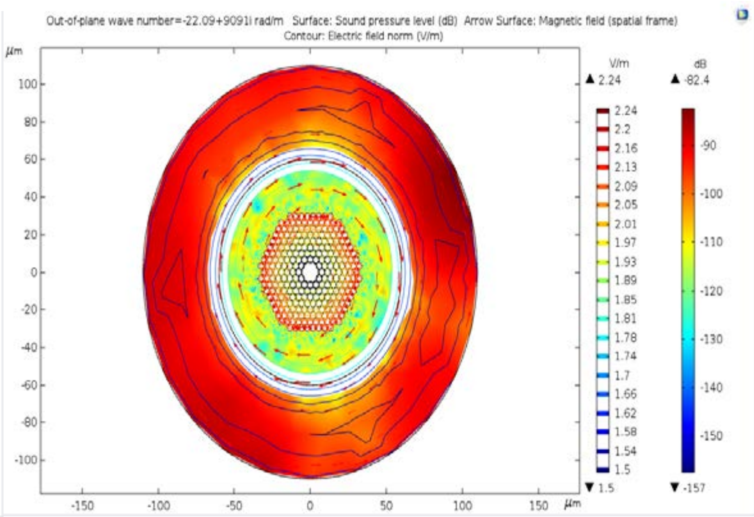


HC 1550-2 PBF Hexagonal Honeycomb

(c) Sound Pressure

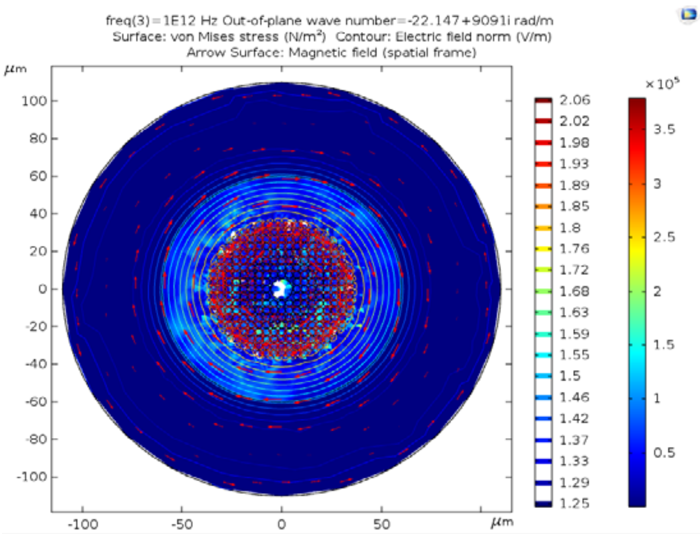


HC 1550-2 PBF_Circular Honeycomb

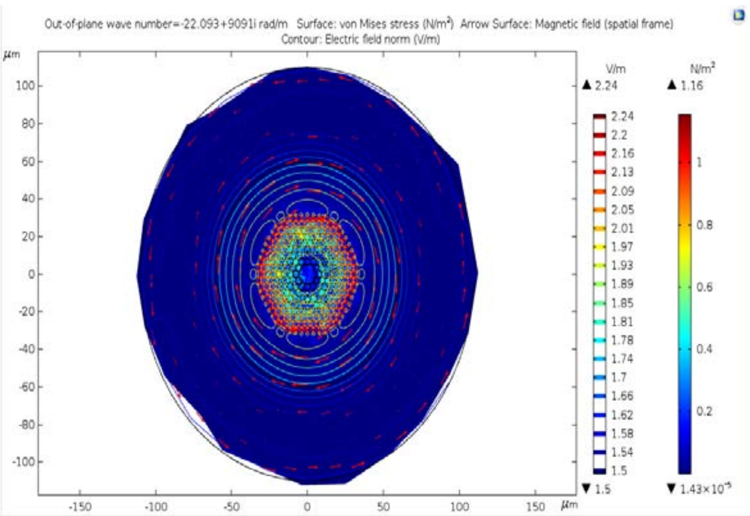


HC 1550-2 PBF_Hexagonal Honeycomb

(d) Stress Level

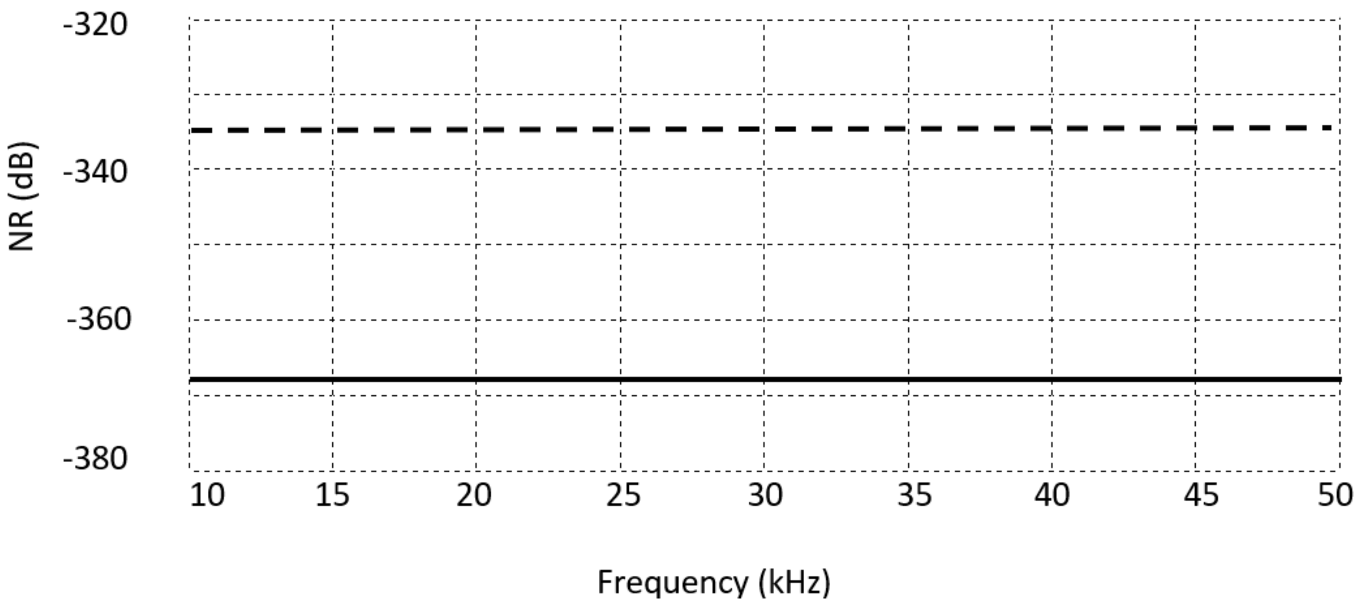


HC 1550-2 PBF_Circular Honeycomb

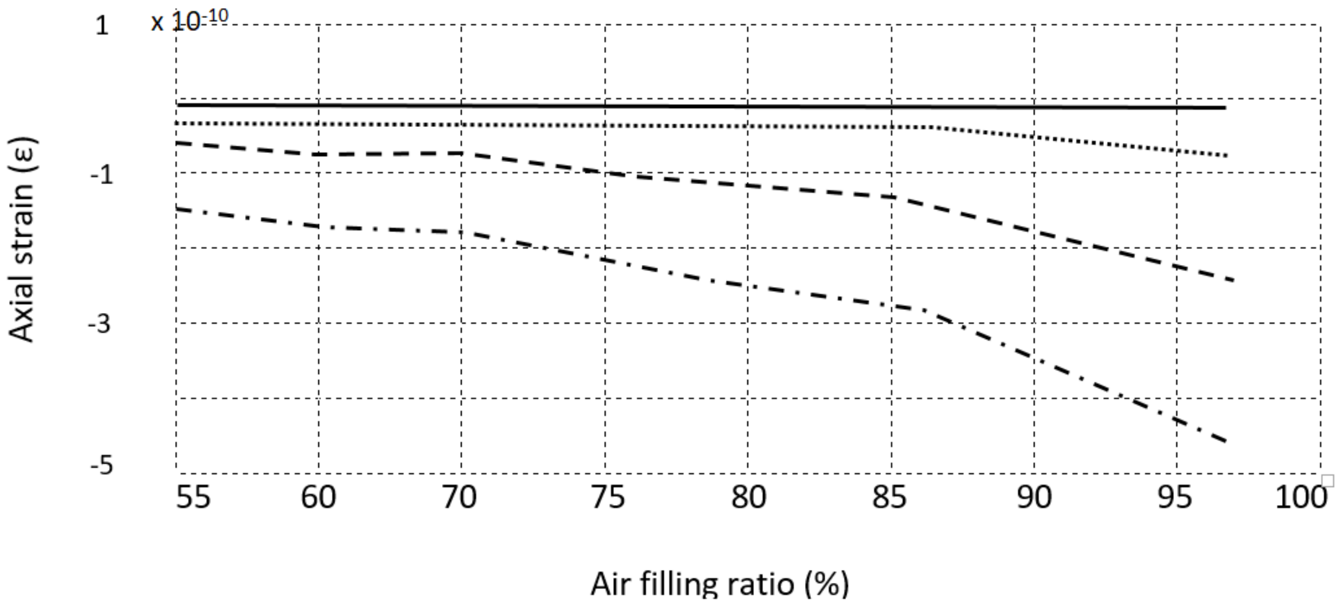


HC 1550-2 PBF_Hexagonal Honeycomb

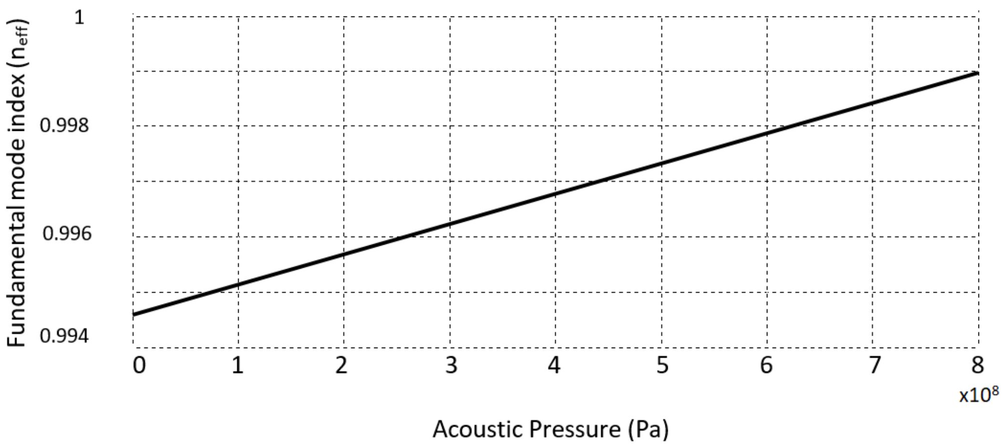
(e) NR of the HC-1550 and SMF as a function of acoustic frequency for acoustic pressure of 1 Pa:



(f) Axial strain of the microstructured region of HC-1550 as a function of η for different acoustic pressures:



(g) The fundamental mode refractive index of the investigated HC-PBF as a function of the acoustic pressure at acoustic frequency 10 kHz:



Conclusion

Optical fiber hydrophone is an important area of research. For many years, researchers have shown the feasibility of using the conventional SMF hydrophones as an alternative to the conventional sound navigation and ranging (SONAR).

Now, extensive research is going on Hollow-Core Photonic Bandgap fiber. By using a thin outer cladding of the order of a few micrometers or less and an air-filling ratio of 95% or higher, it is theoretically possible to enhance the NR of the HC-PBF compared to conventional silica fibers. The reduction in the thickness of the HC-PBF's outer silica cladding would weaken the mechanical strength of the fiber, and this could be an issue when it is used under high static pressure environment such as in deep water. This is a topic of further investigation.

I have tried best to simulate HC-PBF of 1550-2 type having both circular & hexagonal air-silica honeycomb structure using COMSOL multiphysics v5.3 software & presented the corresponding figures & graphs in this report.

[Attachment of larger view of my design microstructure]